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Research Paper
INT-292

May 1982

Models for Describing Vertical Crown Development of Lodgepole Pine Stands

Dennis M. Cole and Chester E. Jensen

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RESEARCH SUMMARY

Interaction models for the dominant crown class were developed for estimating average height to base of crowns (crown height) and average crown length (depth) as a function of stand density and average height of dominant trees — for even-aged lodgepole pine stands in Montana, eastern Idaho, western Wyoming, and northeastern Utah. Separate models are presented for two expressions of stand density (basal area, and crown competition factor) to provide analysts an applicable model for existing data bases regardless of which measure of stand density has been used. Tables of model solutions for representative classes of stand density and height are also provided, along with a supplemental regression equation for estimating height and depth of the total canopy as a function of average crown height and total tree height of dominant trees. Finally, suggestions are made for utilizing the models presented in this paper in computerized stand projection programs. An example is given of vertical crown development in relation to other interactive stand parameters and how these parameters can be expected to vary under different stand management strategies.

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INTRODUCTION

Development of tree crowns and stand canopies is of interest to several forestry disciplines. Mensurationists are interested in it in relation to the amount and distribution of growth among bolewood, branchwood, and foliage of trees and stands. Hydrologists and snow scientists want to know how it relates to the reception and flux of moisture within the aerial and subsurface environments of stands. Silviculturists are interested in it as a process associated with the differentiation of stands into social strata and size distributions, such as height and diameter distributions, that can be manipulated by cultural practices to affect crown development and size distributions within the future stand. Similarly, wildlife and fisheries biologists are interested in how crown and canopy characteristics directly or indirectly influence fish and wildlife.

Although most of these interests are relevant to all forest cover types (Society of American Foresters 1980), our interest here is a single species—lodgepole pine (*Pinus contorta* var. *latifolia*)—and the lodgepole pine cover type where it occurs primarily as pure even-aged stands. Within this context, it is recognized that stand density, age, and site quality are major variables influencing canopy variation among stands.

However, the vertical development of crowns in relation to stand density and age has not been adequately described for lodgepole pine (Gary 1978). We believe this is partly because most attention to crown development (regardless of species) has focused on crown length. Although an important parameter, crown length in a majority of past work has been converted from an absolute measurement unit to crown ratio, a dimensionless relative value, which expresses crown length as a fraction or percentage of total tree height. In addition to obscuring dimensional relationships and our ability to associate them, the expression of crown length as a ratio also masks another important facet of crown development—crown position. Because both crown depth (length) and position relative to the ground are important parameters, we believe they should be examined jointly in terms of their interaction with stand density and age. In pursuing these premises, our investigations have led to a better quantification of these relationships through the development of interaction models and associated relationships and procedures for using them.

METHODS

Data were available from 134 permanent sample plots of a long-term study of stand density effects in natural stands of lodgepole pine. The fixed-area plots were located in even-aged, essentially pure lodgepole pine stands across an extensive geographical area from northeastern Utah to northwestern Montana (fig. 1). The stands represent a broad range of stand characteristics. Basal areas ranged from 30 to 250 ft^2 per acre (1.13 to 57.39 m^2/ha), and mean heights of the dominant crown class (Society of American Foresters 1958) ranged from 21 to 83 ft (6.4 to 25.3 m). Stand ages ranged from 22 to 125 years and site indexes (base 100 years) from 50 to 100.

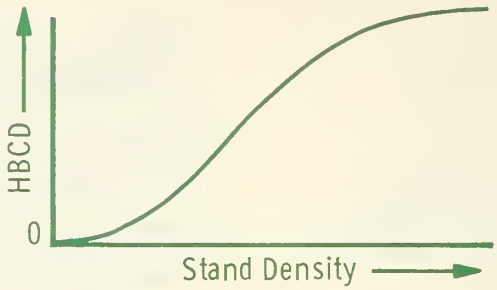
For each plot, mean values of the following variables were available from a 10-tree subsample of the dominant trees on the plot: (1) age at breast height, (2) diameter at breast height (d.b.h.) outside bark, (3) total height, and (4) height to the base of live crown (the crown base was visually balanced to determine the measuring point). To examine the lowest extent of the canopy in relation to the dominant crown class component, 27 of the plots were subsampled to provide mean values of the above-named variables for the suppressed crown class (Society of American Foresters 1958). Plot tallies of all trees divided into 1-inch (2.54-cm) diameter classes were used to compute basal areas. Stand age was determined from increment cores taken at breast height from the 10-tree sample of the dominant crown class, and the stand was checked for the even-aged condition (age range $\leq$ 20 years) by randomly sampling the age of intermediate and suppressed trees.

Figure 1.—Geographic distribution of sample plots.

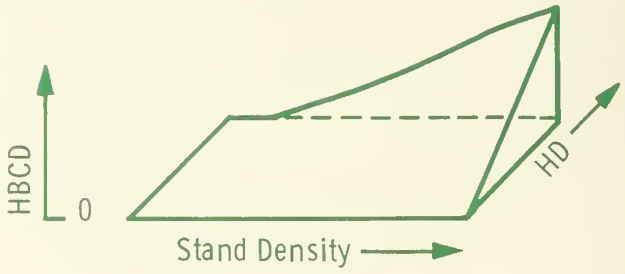
Regression screening of the simple additive effects of basal area (BA), crown competition factor (CCF) (Krajicek and others 1961), average height of dominants (HD), average d.b.h. of dominants (DD), stand age (A), and various transforms and interactions of each, on average height to the base of the crown of dominants (HBCD) revealed reasonably strong, statistically significant ($p = 0.05$) relationships in HBCD = f(BA,HD) and HBCD = f(CCF,HD). A weaker but still significant relationship was also noted for HBCD = f(A,BA).

Because this relationship involved age measured at breast height (A), its use necessitates a conversion to a corresponding total stand age to allow use with stand growth projection programs that project total stand age. For this reason, and the fact that the relationship was weaker, we did not pursue this model. Having established that the relatively simple effects and interactions for BA, CCF, and HD were significant contributions to change in HBCD, potentially more sensitive hypotheses involving these variables were developed. The sources of information for the above were rough expectations, plus finite estimates of interaction developed with half of the data (randomly selected) using the methods of Jensen (1973, 1976, 1979). The basis for expectations and the curve forms postulated are as follows:

In an even-aged stand of lodgepole pine, HBCD is expected to increase sigmoidally upward from zero as stand age and density increases.



Among stands of the same age and site quality, branches near the ground on open-grown trees are not shaded out of existence as they are in more dense stands where trees are competing for light. Thus, at some low to medium density level, shading and HBCD should both begin to increase more rapidly, finally reaching asymtotes at high densities. Among stands of the same age and basal area (where density is high enough that trees are competing for light), differences in site quality can be expected to generate differences in mean dominant tree heights (HD). Because added stand height increases the depth of shade in the stand, the postulated sigmoidal effect of stand density on HBCD is expected to rise in a linear or perhaps relatively flat exponential fashion, with increasing HD.



This major effect may be offset somewhat by the tendency for dominant trees on better sites to maintain lower crown branches longer than their counterparts on poorer sites, all other factors being equal.

The above model was described mathematically and fitted with least squares to the remaining half of the data. It was found by analyses of the residuals to be an effective predictor of that subset of the data. Assuming that a model developed with the same methods on the entire data set would possess more stable parameters, a final model was developed with the combined data for each of two alternative expressions of stand density—basal area (BA) and crown competition factor (CCF) (Alexander and others 1967). Separate models were developed for these two common expressions of lodgepole pine stand density to allow crown depth and position estimates to be made regardless of whether density is expressed as BA or CCF in the data base, or one form or the other is preferred by the analyst.

RESULTS AND DISCUSSION

Applicable Units of Measure

All the mathematical expressions in this paper were developed in English units of measure; therefore, their parameters are applicable and their solutions are correct only with the specified units of the English system.

Average Position and Depth of Dominant Crowns

Basal Area Model

Average height to the base of the crowns of dominant trees (HBCD) was plotted on basal area (BA) by 10-ft (3-m) groups of average dominant tree heights (HD), and the data were found to be distributed such that full sigmoidal effects of basal area (BA) were most apparent in the 30- to 50-ft (9.1- to 15.3-m) HD range (fig. 2). However, because the curve shapes for HBCD over BA were reasonably consistent for all HD groups, they were characterized as a single sigmoidal form[1] operative over the entire range of HD. The maximum heights of the HBCD over BA sigmoids occurred at BA = 250 and defined the upper limits of the interaction model. This parameter, changing over HD and called YP_{BA}, is described by a rather flat exponential curve (fig. 3), after the methods of Jensen and Homeyer (1971). Its mathematical expression is $YP_{BA} = 0.1492 * HD^{1.33}$.

The complete interaction model for HBCD over BA and HD is shown graphically in figure 4. Its mathematical representation is:

$$[1]\quad HBCD = YP_{BA} * (1.0019 * e^{-\left|\frac{BA}{250} - 1.0\right|^{5.5}} - 0.0019) * 0.9786^{2}$$

where: $\overline{HBCD} = 23.3$ ft, $R^2 = 0.82$, and $s_{y \cdot x} \simeq 5.2$ ft, and limits are $50 \leq BA < 250$, and $0 < HD \leq 100$.

Estimated values of HBCD generated from the model for representative levels of BA and HD are presented in table 1.

[1] The unscaled sigmoidal form for HBCD was:

$$1.0019 * e^{-\left|\frac{BA}{250} - 1.0\right|^{5.5}} - 0.0019$$

[2] Least squares scaling coefficient (b_1) — in this case the value of 0.9786 was obtained by fitting the hypothesized relation to the data from which it was partially derived (see section on "Scaling Models to Local Conditions" for determination of b_1 for other data sets).

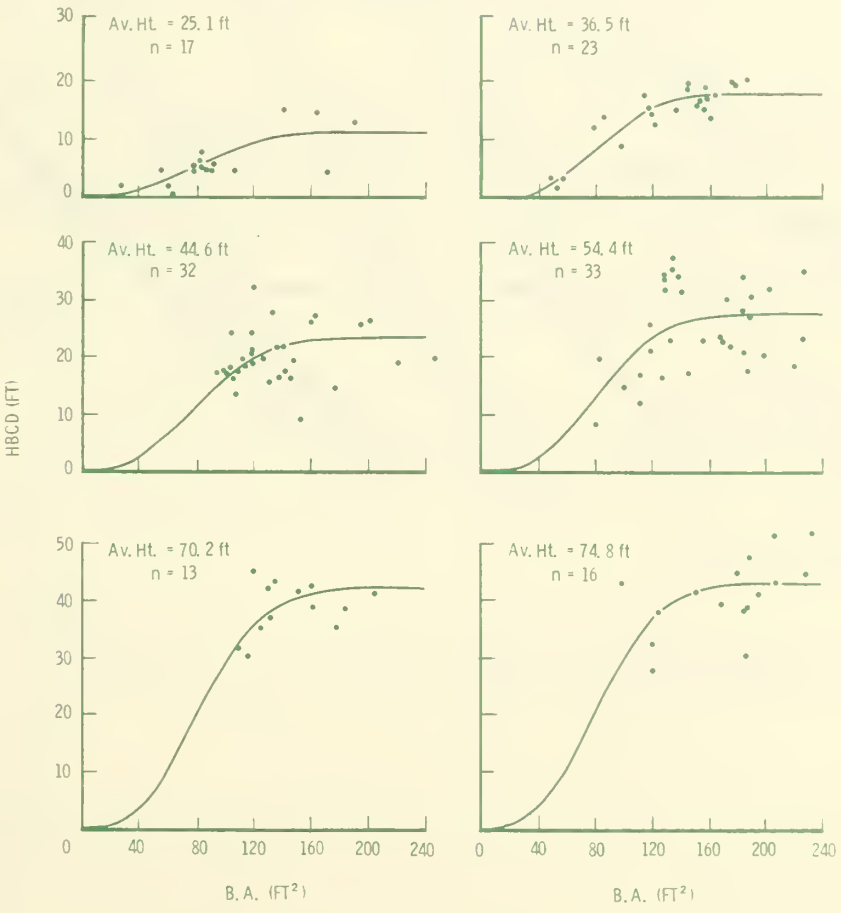


Figure 2.—Sigmoidal effect of BA in HBCD, by tree height groups.

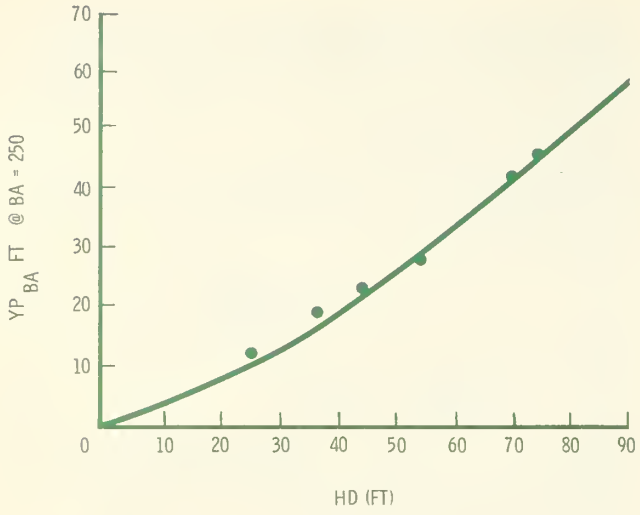


Figure 3.—Maximum height (YP_{BA}) in feet of HBCD over BA sigmoids for the means of 10-foot dominant height classes.

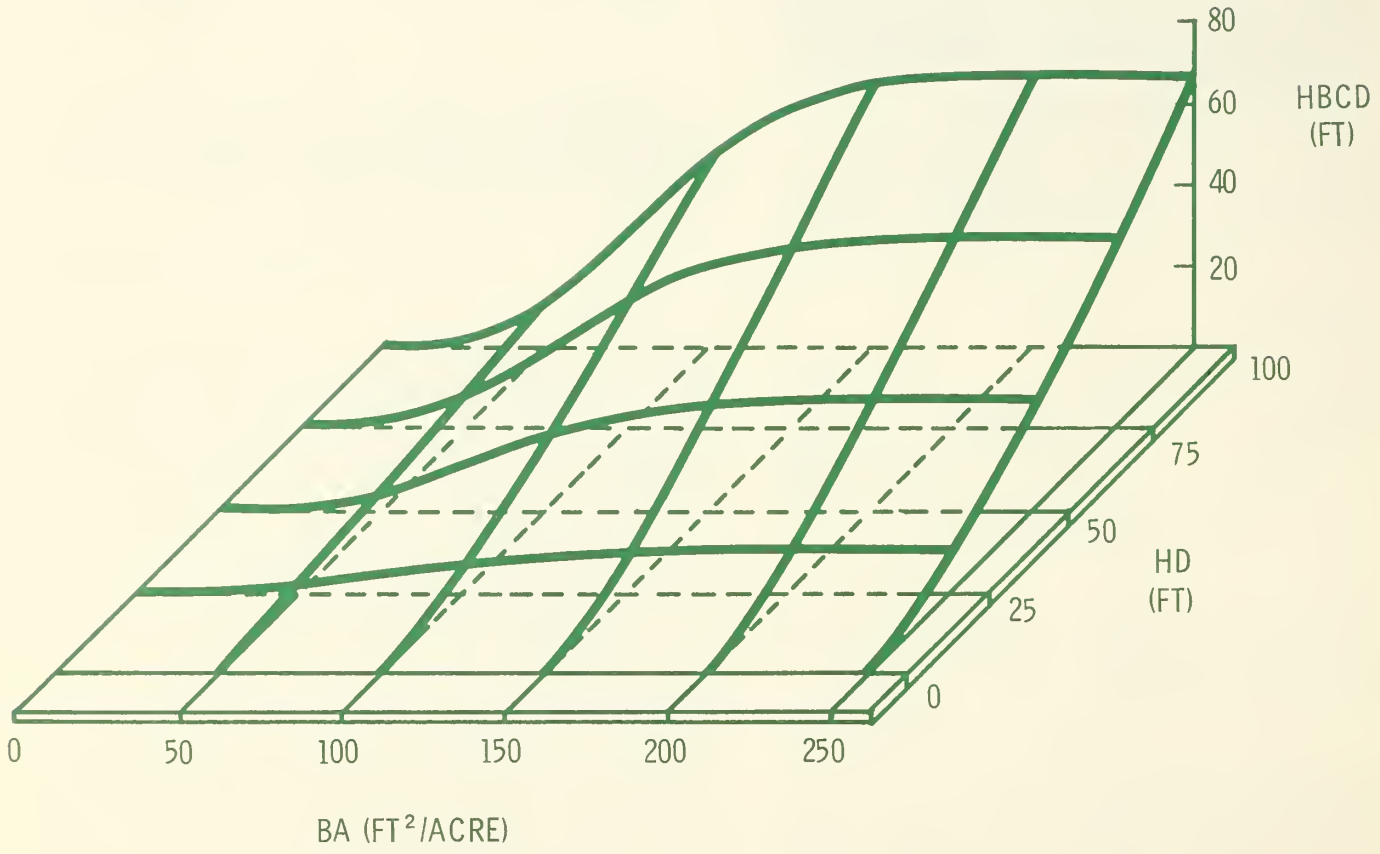


Figure 4.—Height to base of crown (HBCD) as a function of basal area per acre (BA) and average height of dominant trees (HD).

Table 1.—Height to base of crown (HBCD) in feet as a function of basal area per acre (BA) in square feet and average height of dominant trees (HD) in feet[1]

HD	BA						
	25	50	75	100	125	150	175 +
10	0	0	1	2	3	3	3
20	0	1	3	5	7	8	8
30	0	2	6	9	12	13	13
40	1	3	8	14	17	19	20
50	1	4	11	18	23	25	26
60	1	5	14	23	29	32	34
70	1	7	17	28	36	40	41
80	1	8	20	34	43	48	49
90	2	9	24	40	50	56	58
100	2	10	28	46	58	64	66

[1] Values within the block fall within the range of the basic data.

Crown Competition Model

Like BA, the CCF-effect on HBCD was expected to be positive and sigmoidal while the effect of height was again expected to be positive and nearly linear. The data (n = 134) were again separated into 10-ft (3-m) height groups and HBCD was plotted over CCF within each height group (fig. 5).

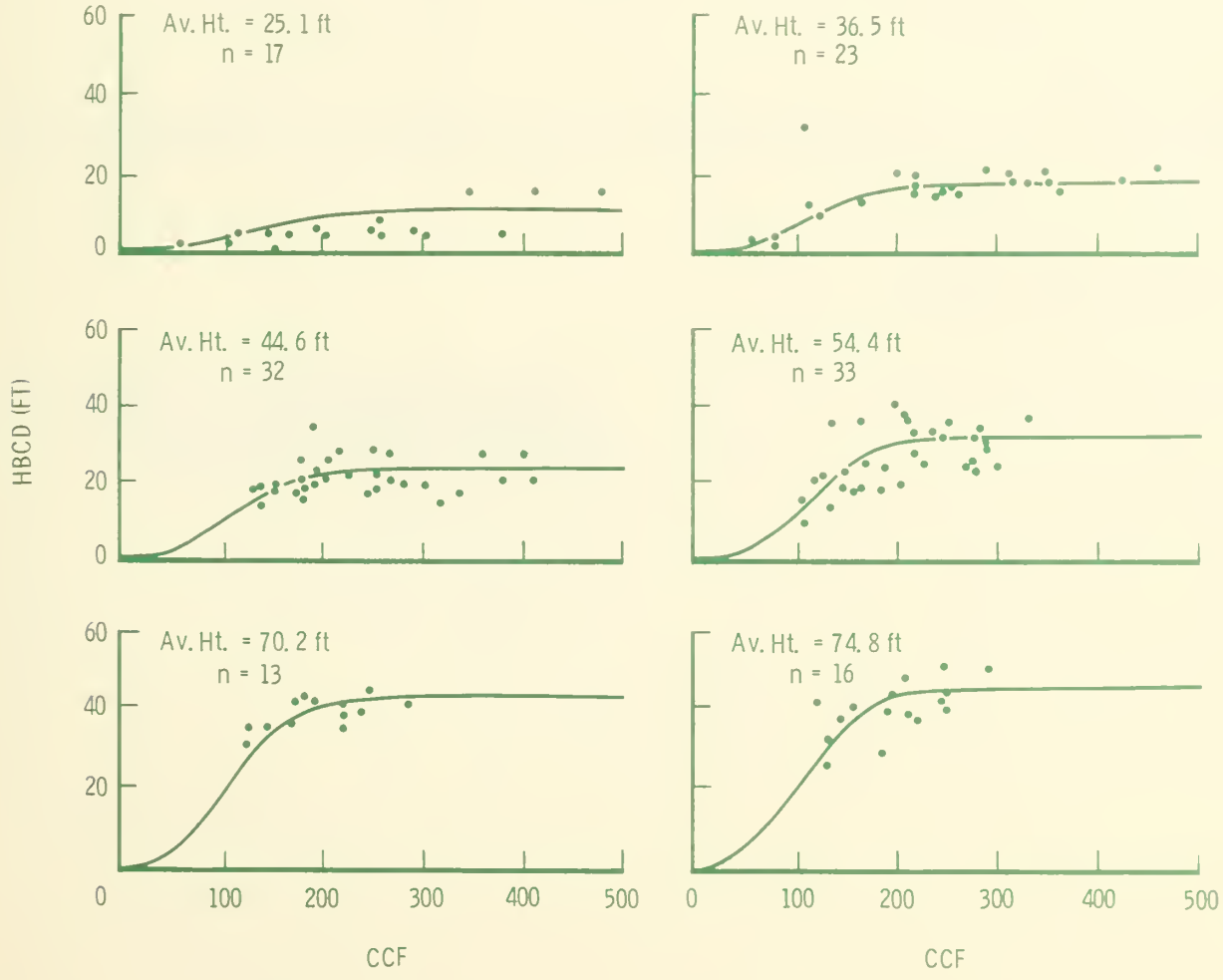


Figure 5.—Sigmoidal effect of CCF on HBCD, by tree height groups.

The expected sigmoidal CCF-effect was clearly visible in the data and appeared to break downward from the asymptotes at about the same point in CCF (180-200) at all heights. As with BA, the strongest expression of the sigmoidal form appeared to exist in the 30- to 50-ft (9.1- to 15.3-m) HD groups. Following Jensen and Homeyer (1970), these sigmoids were well estimated by e^{-K} with n = 10, and $0.183 \leq I \leq 0.190$. Since the range in "I" was slight, I = 0.186 was finally adopted as a compromise for all curves; thus the relationship of HBCD to CCF over the entire range of HD was expressed by a single sigmoidal form.[3]

The maximum heights of the HBCD - CCF sigmoids occurred at CCF-500, which represented the upper limit of model application in CCF. Subsequent to plotting and smoothing the changing maximum heights of the sigmoids over HD, this parameter, called YP_{CCF}, was described after the methods of Jensen and Homeyer (1971) by a slightly concave-upward curve (fig. 6). Its mathematical expression is: $YP_{CCF} = 0.12056\ (HD)^{1.37}$.

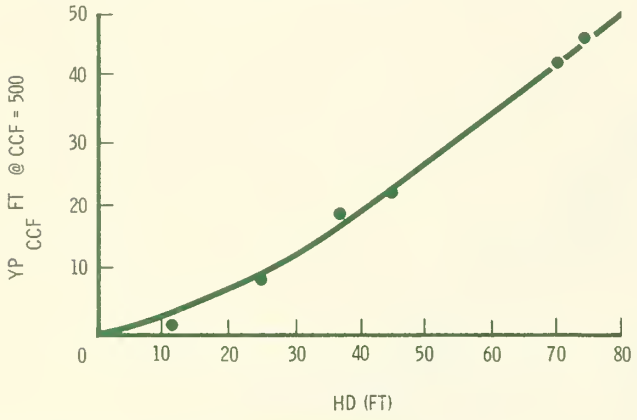


Figure 6.—Maximum heights (YP_{CCF}) in feet of HBCD over CCF sigmoids for the means of 10-foot dominant height classes.

The complete hypothesis is specified as:

$$[2] \qquad \hat{HBCD} = (YP_{CCF}) * e^{-\left|\frac{\frac{CCF}{500} - 1}{0.814}\right|^{10}} * 1.0498^{4/}$$

where: $\overline{HBCD} = 23.3$ ft, $R^2 = 0.85$, and $s_{y \cdot x} \simeq 4.7$ and limits are: $0 \leq CCF < 500$: and $0 \leq HD < 100$.

The model is represented as a response surface in figure 7, and estimated values generated from the model for representative levels of CCF and HD are presented in table 2.

[3] The unscaled sigmoidal form for HBCD was:

$$e^{-\left|\frac{\frac{CCF}{500} - 1}{1 - 0.186}\right|^{10}}$$

[4] Least squares scaling coefficient (b_i) — in this case the value 1.0498 was obtained by fitting the hypothesized relation to the data from which it was partially derived (see section on "Scaling Models to Local Conditions" for determination of b_i for other data sets).

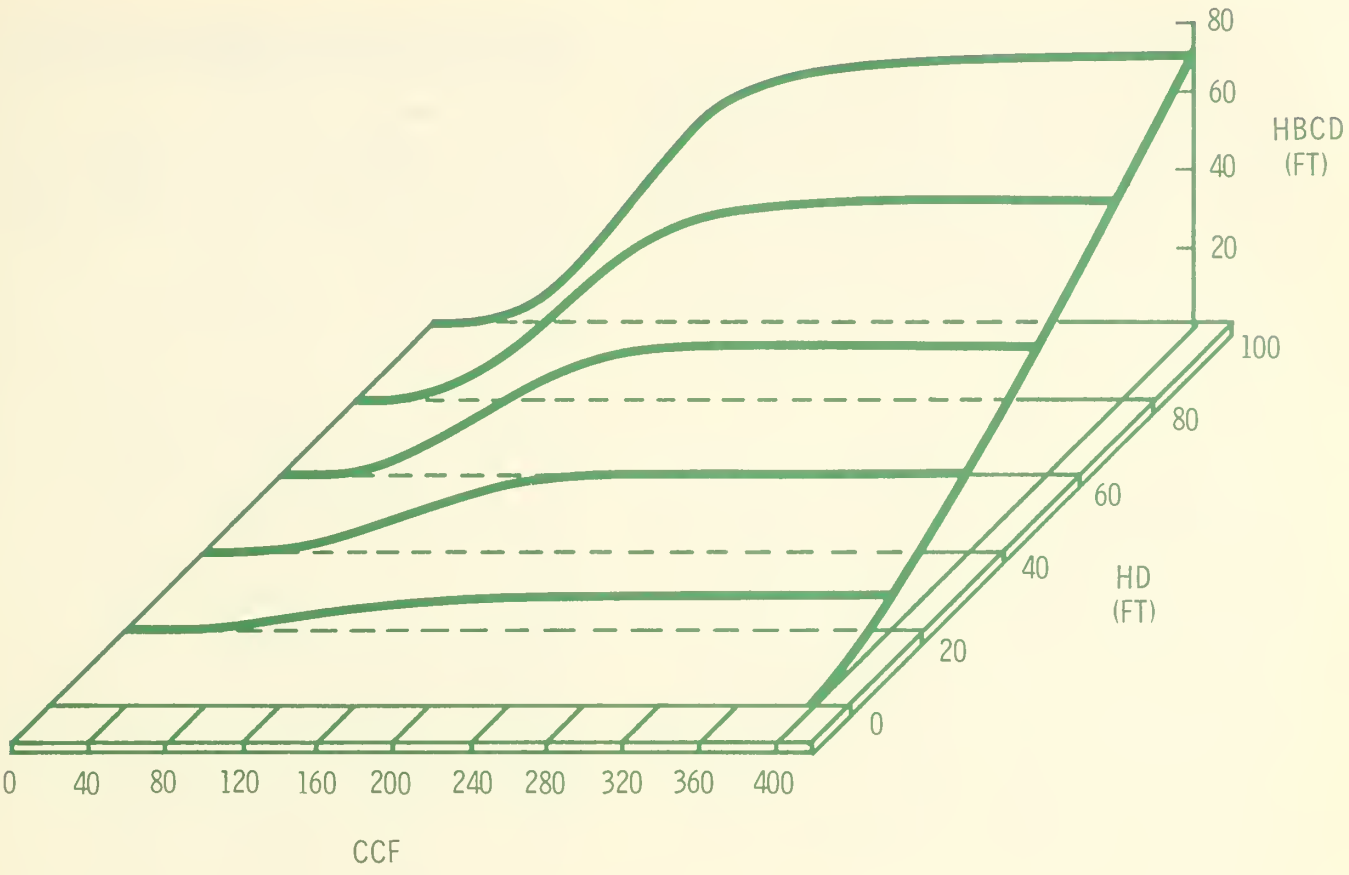


Figure 7.—Height to base of crown (HBCD), as a function of crown competition factor (CCF) and average height of dominant trees (HD).

Table 2.—Average height to base of crown (HBCD) in feet for dominant trees, as a function of crown competition factor (CCF) and average height of dominant trees (HD) in feet[1]

	CCF										
HD	40	60	80	100	120	140	160	180	200	300	500
10	—	—	1	1	2	2	3	3	3	3	3
20	—	1	2	3	5	6	6	7	7	8	8
30	—	2	3	6	8	10	11	12	13	13	13
40	1	2	5	9	12	15	17	18	19	20	20
50	1	3	7	12	16	20	23	25	26	27	27
60	1	4	9	15	21	26	29	32	33	35	35
70	1	5	11	18	26	32	36	39	41	43	43
80	2	6	13	22	31	38	43	47	49	51	51
90	2	7	15	26	36	45	51	55	57	60	60
100	2	8	18	30	42	52	59	64	66	69	70

[1] Values within the block fall within the range of the basic data.

Scaling Models to Local Conditions

The models (equations [1] and [2]) can be adjusted to data sets from other populations of lodgepole pine trees through a simple least squares fitting of model estimates to observed sample values of HBCD (forcing the regression through the origin) to obtain a least squares scaling coefficient (b_i) for each population: $b_i = \Sigma XY / \Sigma X^2$, where X = estimated HBCD, according to equation [1] or [2], and Y = actual HBCD from the pertinent data set.

The value of the coefficient (b_i) is used to scale estimates from equations [1] or [2] to local conditions as shown in equation [3]:

$$[3] \qquad \hat{HBCD}_i = \hat{HBCD} * b_i.$$

Equations [1] and [2] with [3] provide estimates of the average position (height above ground) of dominant tree crowns in natural even-aged lodgepole pine stands, as a function of their stand density and average height of dominant trees. Average depth (length) of dominant tree crowns can be estimated for a stand, following estimation of HBCD, as the difference between the average height of dominant trees (HD) and HBCD. Although the position and depth of the dominant crown class does not indicate the total depth and position of the stand canopy, we believe the dominant parameters can serve as effective statistical indicators of various biological relationships associated with crown characteristics of the overall stand.

Overall Position and Depth of Stand Canopies

To provide further insight into the overall depth and position of lodgepole pine stand canopies, we examined the relationship between average height to the base of crowns of suppressed trees (HBCS) and HBCD, for a 27-stand subsample of the 134 stands used to develop the HBCD models. We found that HBCS in feet can be estimated with the relationship:

$$[4] \qquad HBCS = -4.19 + 0.39\,HBCD + 0.18\,HD$$

$$R^2 = 0.84$$

Therefore, equation [4] can be used subsequent to estimating HBCD, to estimate HBCS — thereby providing an estimate of the position of the overall canopy in relation to height in feet above the ground. Overall estimated depth of the canopy can be calculated as the difference between HD and HBCS for the stand.

Forecasting of Future Characteristics of Lodgepole Pine Canopies

To obtain estimates of the canopy position and depth of a stand at various later ages, reliable estimates of HD and BA or CCF must be possible for those future ages. Realistic values of these parameters can be obtained with computerized tree and stand growth projections for lodgepole pine (Stage 1973; Myers and others 1971; Edminster 1978). The models reported in this paper can also be embedded in such computer programs to provide vertical crown development information in addition to the other stand development information they provide. In embedding the crown models in computer growth projection programs, it is important that stand density reductions (due to invoking thinning subroutines) do not cause crowns to "grow-back-down-the-bole." We prevented this by defaulting the value of HBCD following thinning at any period, to the value calculated from the crown model (equations [1] or [2]) just prior to the thinning. We did this with a stand projection program for lodgepole pine (Myers and others 1971), modified to include growth equations developed from Montana and Idaho stand data (Cole 1971; Cole and Stage 1972; Stage 1975). We found that equations [1] and [2] gave similar results under natural stand development; however, when low thinnings were simulated, equation [2] gave less realistic results. We believe this might be due to the change in tree numbers and their diameter distribution being inconsistent with the regression coefficients of the CCF equation for lodgepole pine (Alexander and others 1967). This equation was developed from unmanaged stand data and relates total crown coverage of natural stands to the number and size of open grown trees necessary to obtain 100 percent crown coverage. Basal area, on the other hand, can be accurately calculated regardless of changes in the diameter distribution of the stand, because of its direct mathematical relationship to number and diameters of trees.

Because the CCF values are influenced by thinning (particularly by repeated low thinnings that systematically skew-upward the diameter distribution), we recommend that only equation [1], the crown model involving basal area as the stand density measure, be used to preview crown development under thinning and other managed-stand scenarios.

An example of the results using equation [1] to preview yield and other effects is summarized in table 3 for stand densities of 2,000 and 8,000 trees/acre (4 940 and 19 760/ha), and for no-thinning contrasted with both a single precommercial thinning and precommercial thinning with subsequent commercial thinnings.

Table 3 indicates that, among other effects, heights and crown lengths (canopy depth) are increased over time by repeated thinnings when compared to no-thinning. However, height to crown (canopy position) is also elevated by repeated thinnings, in comparison to no-thinning, because the removal of suppressed trees in low thinnings removes this portion of the overall canopy. Repeated computer trials of this kind can reveal a favorable (if not optimum) management regime for attaining or maintaining specified values of these important stand parameters during stand development.

Table 3.—Stand development under different management for two contrasting initial stocking levels 2,000 and 8,000 trees/acre (4 940 and 19 760/ha) in lodgepole pine on site index$_{100}$ = 60 lands in Montana and Idaho

	Age	Management status[1]	No. trees/ acre	Average stand diameter	Basal area	Average dominant height	Dominant crown height	Dominant crown length	Dominant crown ratio	Net merchantable[2] volume	Mechantable volume cut
	Years			*Inches*	*Ft²*	— — — — *Feet* — — — — —				*Ft³*	*Ft³*
Initial stocking = 2,000 trees/acre (4 940/ha)	20	N	2,000	2.4	63	14	1	13	0.93	—	—
		P	473	3.1	25	16	1	15	.94	—	—
		C	473	3.1	25	16	1	15	.94	—	—
	50	N	1,525	3.9	127	31	12	19	.61	—	—
		P	458	6.1	93	35	10	25	.71	1,130	—
		C	332	6.5	77	36	10	26	.72	990	140
	80	N	1,163	5.0	159	45	23	22	.49	1,810	—
		P	415	7.5	127	49	23	26	.53	2,520	—
		C	227	8.8	96	50	22	28	.56	2,020	370
	110	N	888	5.9	169	57	31	26	.46	3,280	—
		P	358	8.7	148	61	33	28	.46	3,800	—
		C	157	10.8	100	63	29	34	.54	2,700	450
	140	N	681	6.8	172	66	38	28	.42	4,370	—
		P	298	9.7	153	70	40	30	.43	4,620	—
		C	142	12.2	115	72	35	37	.51	3,630	—
Initial stocking = 8,000 trees/acre (19 760 ha)	20	N	8,000	1.4	86	10	2	8	0.80	—	—
		P	539	2.3	16	14	2	12	.86	—	—
		C	539	2.3	16	14	2	12	.86	—	—
	50	N	5,664	2.4	178	26	11	15	.58	—	—
		P	523	5.7	93	34	10	24	.71	1,010	—
		C	349	6.2	73	35	10	25	.71	890	120
	80	N	3,281	3.3	195	41	20	21	.51	—	—
		P	472	7.1	130	48	23	25	.52	2,450	—
		C	239	8.5	94	49	21	28	.57	1,930	340
	110	N	1,998	4.2	192	52	28	24	.46	—	—
		P	403	8.3	151	60	33	27	.45	3,780	—
		C	163	10.6	100	62	29	33	.53	2,660	480
	140	N	1,324	5.1	188	61	35	26	.43	3,080	—
		P	332	9.3	157	69	40	29	.42	4,630	—
		C	147	12.0	115	71	34	37	.52	3,580	—

[1] Management status: N = unthinned, P = precommercial thinning at age 20 to growing stock level (GSL) 80 (Myers 1967), C = thinning at age 20 to GSL 80 and at 30-year intervals to GSL 100.

[2] Merchantable cubic foot volume in trees 4.6 inches d.b.h. and larger to 4.0-inch top.

PUBLICATIONS CITED

Alexander, R.: Tackle, D; Dahms, W. Site indexes for lodgepole pine with corrections for stand density: methodology. Res. Pap. RM-29. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967, 18 p.

Cole, D. M. A cubic-foot stand volume equation for lodgepole pine in Montana and Idaho. Res. Note INT-150. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 8 p.

Cole, D. M.; Stage, A. R. Estimating future diameters of lodgepole pine trees. Res. Pap. INT-131. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1972. 20 p.

Edminster, C. B. RMYLD: computations of yield tables for even-aged and two-storied stands. Res. Pap. RM-199. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1978. 26 p.

Gary, H. L. The vertical distribution of needles and branchwood in thinned and unthinned 80-year-old lodgepole pine. Northwest Sci. 52(4): 303-309; 1978.

Jensen, C. E. Matchacurve-3: multiple component and multidimensional mathematical models for natural resource studies. Res. Pap. INT-146. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 42 p.

Jensen, C. E. Matchacurve-4: segmented mathematical descriptors for asymmetric curve forms. Res. Pap. INT-182. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1976. 16 p.

Jensen, C. E. e^{-K}, a function for the modeler. Res. Pap. INT-240. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1979. 9 p.

Jensen, C. E.; Homeyer, J. W. Matchacurve-1 for algebraic transforms to describe sigmoid- or bell-shaped curves. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1970. 22 p.

Jensen, C. E.; Homeyer, J. W. Matchacurve-2 for algebraic transforms to describe curves of the class X^n. Res. Pap. INT-106. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1971. 39 p.

Krajicek, J. E.; Brinkman, K.; Gingrich, S. Crown competition — a measure of density. For. Sci. 7(1): 35-42; 1961.

Myers, C. A. Yield tables for managed stands of lodgepole pine in Colorado and Wyoming. Res. Pap. Rm-26. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1967. 20 p.

Myers, C. A.; Hawksworth, F.; Steward, J. Simulating yields of dwarf mistletoe-infested lodgepole pine stands. Res. Pap. RM-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station; 1971. 15 p.

Stage, A. R. Prognosis model for stand development. Res. Pap. INT-137. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1973. 32 p.

Stage, A. R. Prediction of height increment for models of forest growth. Res. Pap. INT-164. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1975. 20 p.

Society of American Foresters. Crown classes follow standard definition — forestry terminology: a glossary of technical terms used in forestry, 3d ed. Washington, DC: Society of American Foresters; 1958.

Society of American Foresters. Forest cover types of the United States and Canada. Washington, DC: Society of American Foresters; 1980. 148 p.

Cole, Dennis M.; Jensen, Chester E. Models for describing vertical crown development of lodgepole pine stands. Res. Pap. INT-292. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station; 1982. 10 p.

Interaction models are presented for describing height and depth of crowns, of the dominant crown class of lodgepole pine stands as a function of total stand height and either basal area or crown competition factor. A regression model is also presented to provide estimates of total canopy depth and position. Suggestions are made for using the models in computer simulations; and an example given of how vertical crown parameters change in relation to other stand parameters, under different management situations.

KEYWORDS: crown models, crown development, canopy depth, canopy position, lodgepole pine

☆ U.S. GOVERNMENT PRINTING OFFICE: 1982—576-026/150 REGION No. 8

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